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TITLE: DESIGN AND CONSTRUCTION OF A SHORT-PULSE FRONT END FOR A LARGE CO_2 LASER

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Design and construction of a short-pulse front end for a large CO_2 laser

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Abstract

A CO_2 laser oscillator, switch out, and preamplifier system which produces 1 ns pulses of 10.6 μm light with an energy of about 1 joule was designed and constructed. Commercial CO_2 TEA devices were used throughout. Alignment was simplified by using a single He-Ne laser and penta prism reflectors on kinematic mounts. Performance of this system as compared with calculations with the Laser Optical Train Simulation (LOTS) program will be discussed.

Introduction

A short pulse laser system capable of moderate energy output based on commerical laser devices was designed and constructed. This laser system was to be used as a "front end" of a larger laser facility for experimental study of the interaction of high intensity 10.6 μm light with matter. The design of the front end laser system was based on analytical calculation as well as the Laser Optical Train Simulation (LOTS)[1] computer program. The actual laser performance agree very favorably with LOTS calculations based on educated guesses of the laser amplifer and saturable absorber performance. No attempt was made to recalculate, based on experience to enhance the agreement. The guesses for amplifier and saturable absorber performance were based on the extensive experience in the operation of the Gemini and Helios laser facilities.[2]

Design considerations

The basic constraints on the design of this laser system were dictated by space available, output energy required, reliability, alignment ease, prepulse suppression, damage thresholds, and retropulse protection. Since space was of importance and internal alignment stability of the system paramount, the laser system was built on a single 5'x16'x18" NRC optical table.[3] The output energy necessary to realize the full potential of the main power amplifiers to be used in the final facility was 0.5 J. We, therefore, tried to design a front end capable of 1 J output for a margin of loss in transmission and error in calculation. Availability of transversely-excited-atmospheric pressure (TEA) laser amplifiers from commerical souces with long life and reliable operation led to the decision to use as many commerical devices as possible and to forgo the development beyond state-of-the-art. Actual performance of these TEA devices was quite good. Alignment of the system was designed in from the beginning by including a Ne laser with rotatable penta prisms to align the red beam with the CO_2 beam. For most experiments it is necessary to reduce prepulse energy to a minimum in order to keep a plasma from forming on the surface of the target prior to arrival of the laser pulse. Suppression of prepulse in the front end was accomplished by gas cells which utilized SF_6 as a saturable absorber. This gas strongly absorbs 10.6 μm radiation at intensity levels below a threshold and then becomes highly transparent at higher intensity levels. Two gas cells were used. During each stage of amplification, care must be exercised to keep the beam energy from damaging the optics. Since this system was to be used as a front end for a large laser, care also was taken to assure that any pulse travelling back from the target (retropulse) would be suppressed to a level to protect the optics.

The actual design was finalized based on Gaussian optics calculations for focal length and position of the lenses and mirrors, Franz-Nodvik[4] calculation of gain of the amplifier chain, and the assumption of saturated transmission for the gas cells. Critical parameters assumed are those given in Table 1. When a satisfactory system was developed using these hand calculations, the system was modeled using the LOTS program. This computer program treats the diffraction propagation of the beam and saturable absorbers in a much more detailed fashion. Table 2 gives the parameters used for the LOTS calculation.

Table 1: Parameters Used to Design the Laser System.

Parameter	Assumed Value
Gain of TEA Amplifier*	$0.045\ cm^{-1}$
Saturation Flux*	$55\ mJ/cm^2$
Maximum Intensity Transmitted by unfiltered air with 1 nsec pulse*	$10\ J/cm^2$
Maximum Intensity Transmitted by dry, filtered air with 1 nsec pulse*	$20\ J/cm^2$
Damage Threshold for coated optics (1 nsec)	$1\ J/cm^2$
Damage Threshold for metal mirrors (1 nsec)	$10\ J/cm^2$
Absorption of SF_6 for intensities greater than $1\ mJ/cm^2$	$0.2 \times 10^{-2}\ torr^{-1}\ cm^{-1}$

*At an atmospheric pressure of 580 Torr.

Table 2: Parameters Used to Model the Laser Chain Using LCTS.

Parameter	Value
Gain	$0.045\ cm^{-1}$
Saturation Flux	$55\ mJ/cm^2$
Saturation Irradiance	$2.0 \times 10^{-4}\ J/cm^2$
Log-Log Slope	1.4

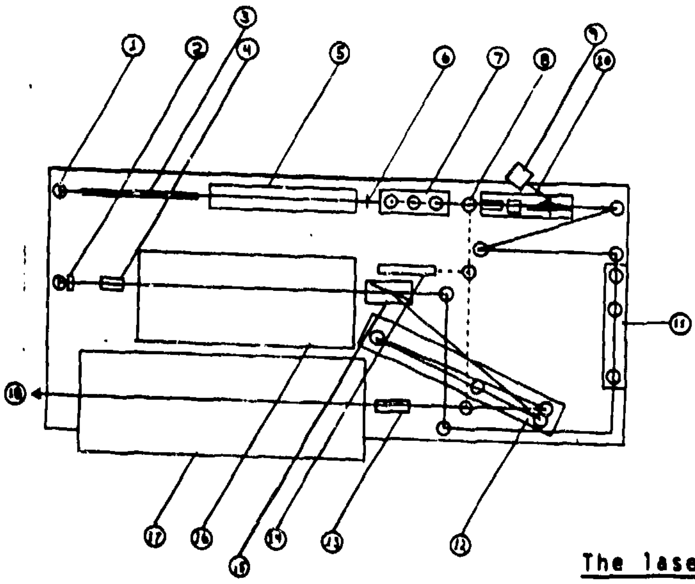

Figure 1: Layout of front end system on 5 x 16 ft table.

1. Oscillator cavity reflector, 6 m radius of curvature.
2. One-quarter wave plate.
3. Plasma smoothing tube.
4. Saturable absorber cell
5. Tachisto 215 TEA amplifier
6. Oscillator output coupler.
7. Spatial Filter 1.
8. Penta prism mount for directing Ne laser.
9. Laser triggered spark gap.
10. Switch out, consists of two polarizers and a CdTe crystal.
11. Spatial Filter 2.
12. Spatial Filter 3.
13. Saturable absorber cell.
14. Ne alignment laser.
15. Wedged Ge Plate.
16. Lumonics K922-S TEA amplifier
17. Lumonics 142 TEA amplifier.
18. Output of front end.

The laser system

Figure 1 shows the layout on the table of all of the components which made up the laser system. The Tachisto[5] model 215 TEA device was used in conjunction with a 2.5 m cavity and a 60 cm low pressure plasma tube to form the oscillator for the system. The 1 nsec pulse is then switched out of the 100 nsec FWHM gain-switched spike which is output from the oscillator. This method of short pulse generation was chosen over a mode locked oscillator based on the superior operation of the Helios front end. In operation, the plasma tube was excited below lasing threshold but had enough gain to allow lasing to start before the gain of the TEA amplifier reaches peak. This allows operation in the TEM_{00} mode and a single longitudinal mode because the gain of the plasma tube is very narrow in frequency. When the full gain of the TEA is reached the width of the gain in frequency is large enough to support several modes, due to operation at atmospheric pressure, but the TEM_{00}, single longitudinal mode wins out over the competing modes because of the gain of the plasma tube. In this configuration the oscillator lases predominantly on the 10.6 μm P20 line.

The first spatial filter, SF1, cleans the beam and also protects the Pockel's cell crystal. SF1 consisted of a 25.4 ZnSe cm focal length lens, a 950 μm pinhole and a 25.4 cm ZnSe recollimating lens. If there is mode-beating in the oscillator output, usually due to having the cavity length improperly set for a P20 longitudinal mode, high power peaks are output by the oscillator. The pinhole for SF1 was chosen so that the smooth, single mode beam would be transmitted, but at nearly the breakdown threshold for the dry-filtered air which was flowed by the pinhole. When the mode-beating was severe, this pin-hole broke down and would not transmit the beam. No damage to the sensitive, expensive CdTe Pockel's cell crystal was noticed even though several output couplers were ruined due to mode-beating.

The beam next passes through a polarizer, a CdTe Pockel's cell, and then is rejected by a second polarizer. These polarizers were made from stacks of 6 Ge plates at Brewster's angle. The plates were arranged three on a side set oppositely so as not to deflect the beam. From the second polarizer the main part of the beam is reflected to the laser-triggered spark gap (LTSG). Both the LTSG and Pockel's cell were manufactured by II-VI.[6] When light of sufficient intensity enters the LTSG, it fires, launching an approximately 1 nsec pulse down a cable which is connected to the Pockel's cell. This pulse causes the CdTe crystal to rotate the plane of polarization of the light passing through it and this light is then transmitted by the second polarizer. The net result is that a 1 nsec pulse is switched out of the longer oscillator pulse. This process may be repeated several times to increase the contrast ratio of the pulse but our system was never operated with more than one Pockel's cell. The first polarizer, while seemingly unnecessary because the output of the oscillator is polarized due to the Brewster angle windows on the plasma tube and TEA amplifier, is used to prevent oscillation of the Lumonics K922-S.[7] Without this polarizer the Lumonics K922-S amplifier did oscillate off of the oscillator cavity output coupler and some other surface. This is a very danerous mode since it includes the Pockel's cell and could damage it.

After being switched out the beam is cleaned up and mode matched to twice the diameter by a spatial filter (SF2). This spatial filter consisted of a 12.7 cm focal length ZnSe lens, a 500 μm pinhole and a 25.4 cm ZnSe recollimating lens. The beam entering has a nominal diameter of 1 cm and exits with a nominal diameter of 2 cm. This spatial filter is operated in unfiltered room air because only about 1 mJ is passed forward and it is easily broken down by any large retropulse.

The beam is next amplified by two passes of the Lumonics K922-S TEA amplifier. This is accomplished through polarization switching of the beam. The beam is passed by a wedged Ge plate at Brewster's angle and amplified by one pass of the Lumonics K922-S. It then is transmitted by an SF_6 gas cell which is used to isolate the gain of this amplifier. Next the beam transmits a 1/4 wave plate which changes the plane polarized light to circularly polarized light. This circularly polarized light is then reflected back through the 1/4 wave plate. The result of the two passes through the 1/4 wave plate is the same as a single pass through a 1/2 wave plate and the final beam is plane polarized but the plane of polarization is rotated 90°. After another pass through the gas cell and the gain region the beam is reflected by the Ge plate with high, ~ 80%, efficiency. The beam is then directed to the next spatial filter, SF3.

SF3 was designed to use metal mirrors rather than lenses. At this point damage due to the forward going beam would not damage coated optics but a retropulse might. Therefore, the higher damage threshold of metal mirrors was used to advantage. This spatial filter also mode matches the beam up to 3 cm diameter and consists of a 1.0 m radius of curvature spherical mirror, a 1.0 mm pinhole and a 1.5 m radius of curvature spherical recollimating mirror. This spatial filter proved to be the greatest problem area in the operation of the front end. This is because the Ge plate was wedged so that only the first reflection from the Ge plate would make it through the pinhole. Unfortunately, it was not wedged enough that the second reflection was far away from the pinhole and the second reflection, which contains 16 of the energy output by the K922-S, produced a plasma on the surface of the pinhole. This plasma then induced breakdown of the pinhole by the energy in the first reflection by UV ionization of the air in the pinhole. The net result was closing of the pinhole in SF3 by the forward going pulse and a net transmission of only about 40% of the energy out of the K922-S. Much effort was expended trying to properly align SF3 before the true mechanism of this breakdown was established.

The beam next traverses another SF_6 gas cell and is amplified by the Lumonics 142 amplifier. The gas cell effectively isolates the gain of the 142 from that of the K922-S. It worked quite well in practice and there was never an oscillation including the 142 and K922-S. The output beam of the 142 constitutes the output from the front end.

Comparison of performance to calculation

Table 3 gives the comparison betweeen calculation of the energy output and actual measured outputs. After the two passes of the Lumonics K922-S and reflection off of the wedged Ge plate agreement, as far as energy output, for the LOTS calculation is quite good. The poor agreement for the final output is due to the poor transmission of SF3 as previously noted. Without the pinhole of SF3 in place energy outputs as high as 1.2 J were observed. Figure 2 shows the LOTS calculated near-field intensity pattern. Pictures of the flash from a graphite block hit by the near field front end beam showed a bright central spot with three rings which is quite similar to what would be expected from Figure 2. Further comparison was not done.

Table 3: Comparison of Calculation to Actual Performance for Laser Energy.

Position	Hand Calculation (mJ)	LOTS (mJ)	Actual (mJ)
After SF2	0.5*	0.5*	0.8
After reflection by Ge plate	74	170	150
After SF3	59	168	62
Final output	580	850	450

*Assumed.

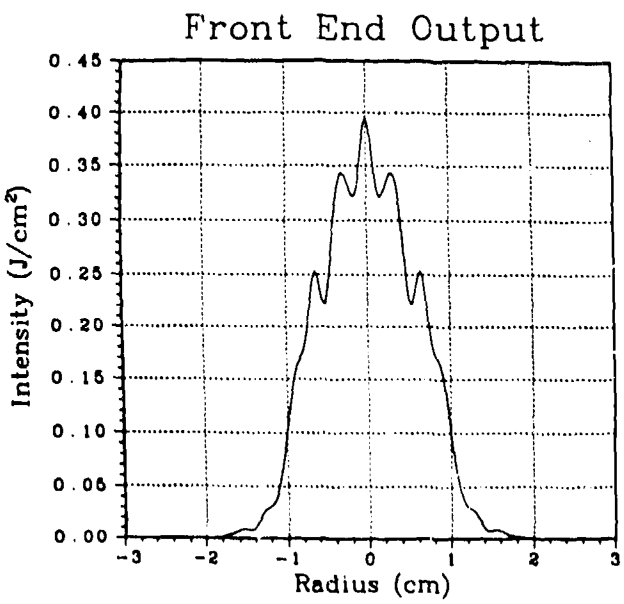

FIGURE II: LOTS calculated front end output in the near field.

Figure II: LOTS calculated front end output in the near field.

Conclusion

It is evident from this work that a few simple rules of thumb can be utilized to successfully design a CO_2 laser system. The many features of the LOTS program make it an excellent tool for predicting the performance of a laser system. The state-of-the-art of TEA laser amplifiers and optics for 10.6 μm light make standard components sufficient for 10^9 watt operation with 1 nsec pulses.

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